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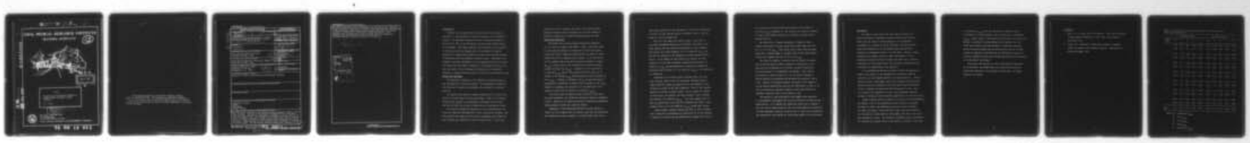

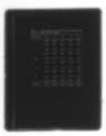

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ALTERATION OF RESPIRATORY RESPONSE TO CARBON DIOXIDE FOLLOWING DIVING TRAINING

J.M. Young

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The respiratory responses to CO_2 inhalation were determined in subjects before diver training. The subjects were Hospital Corpsmen who had either never previously been exposed to the hyperbaric environment or had not dived for at least four months. They then attended the 1st Class Diver School at the USN School of Diving and Salvage, in which seven subjects passed and five failed the course. Those subjects who were successful were re-examined on completion of their training. The data support previous findings that adaptation to the

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hyperbaric environment occurs, particularly in a decrease of the sensitivity to CO_2 inhalation. Sensitivity to hypoxia is much less affected. The subjects who did not complete diver training had a greater mean initial respiratory response to CO_2 inhalation than those who passed the course. It is suggested that the sensitivity to CO_2 of a diver trainee is negatively correlated with his likelihood of success in training.

Carbon dioxide

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INTRODUCTION

Previous work has demonstrated a reduction in the respiratory sensitivity to CO_2 inhalation in subjects exposed to serial hyperbaric exposure. The hyperbaric exposure used was a simulated standard air dive to 66 ft (20.1 m) for 50 minutes, the dive being repeated weekly for two months. This regime produced a mean reduction of 23.3 percent in the slope of the CO_2 response curve in the absence of hypoxia. Sensitivity to hypoxia was variable but showed an overall mean increase in sensitivity after the hyperbaric exposure period. Experiments were designed to provide information as to the maximum alteration in respiratory sensitivity that might be produced if the hyperbaric exposure had been more severe or more prolonged by determining the respiratory responses of subjects before and after a period of more intensive diving.

METHODS AND PROCEDURES

The respiratory responses to CO_2 inhalation and moderate hypoxia were determined by a four-point method. Full experimental methods and the derivation of respiratory parameters are contained in a previous study (2).

The subjects were Hospital Corpsmen attending the 1st Class Diver School at the USN School of Diving and Salvage. Eight of the subjects had never been exposed to the hyperbaric environment and the other four had not dived for at least 4 months prior to starting the course.

All subjects attended the laboratory on two occasions before the course for duplicate determinations of their respiratory responses. The seven subjects who passed the course were re-examined twice during the week following the completion of their diving activity. Of the five

subjects who did not complete the course, four had had minimal hyperbaric exposure and the remaining one could not arrange to attend the laboratory so repeat determinations were not made.

RESULTS AND DISCUSSION

The values for S_1 and the derived respiratory parameters A, B, C, and D are shown in the Tables. Table 1 shows the values of the successful subjects (a) before and (b) after the diving course while Table 2 shows the values before the course for those subjects who did not complete diver training. S_1 is the slope of the CO_2 response line at an end-tidal partial pressure of oxygen (P_{A,O_2}) of about 130 torr and is measured in l/min/torr partial pressure end-tidal CO_2 (P_{A,O_2}). Parameter B is the intercept of S_1 with the P_{A,CO_2} axis at zero expired ventilation ($\dot{V}_E$); it is related to the resting P_{A,CO_2} when breathing air and is measured in torr P_{A,CO_2}. Parameter C represents the P_{O_2} at which the hypoxic stimulation to respiration is maximal and is measured in torr P_{A,O_2}. Parameter D represents the sensitivity to CO_2 inhalation in the absence of hypoxia and is measured in l/min/torr P_{A,CO_2}.

The results show the expected large variability, both inter- and intra-individual, the variability being most marked in parameters A and C. Results do not reveal statistically significant differences between groups of people but trends are marked.

Examination of the determinations before diving training in Tables 1(a) and 2 suggest that the subjects come from two populations. The candidates who were successful in training (Table 1(a)) have a

lower mean sensitivity to CO_2 inhalation (D) and a lower sensitivity to hypoxia (A) than the *unsuccessful candidates* (Table 2) and also exhibit a relative acidemia (B).

Table 1(a) also shows that subject number 7 has values of respiratory parameters which are very different from those of the other subjects who were eventually successful in diver training. This subject had a mean parameter D of 5.0 l/min/torr P_{A,CO_2} and was twice as sensitve to CO_2 inhalation as another subject in this series. If the results on this subject were ignored, the mean parameter D of the other successful candidates would become 1.73 l/min/torr P_{A,CO_2} and would approach a statistically significant difference from the mean D of 2.42 l/min/torr P_{A,CO_2} of the *unsuccessful candidates*.

Comparison of the results before training, Table 1(a), and after training, Table 1(b) of the successful candidates shows a slight reduction in mean CO_2 sensitivity (S_1 and parameter D) and virtually no change in the other parameters. Most of this apparent adaptation occurred in subject number 7 and if, again, the results on this subject were ignored, the mean parameter D after training would become 1.82 l/min/torr P_{A,CO_2}. This would suggest that the mean CO_2 sensitivity of the other six candidates had tended to rise slightly from 1.73 to 1.82 l/min/torr P_{A,CO_2} during their course.

Subject number 7 showed a marked adaptation to diver training with a reduction in non-hypoxic CO_2 sensitivity (D) of 40.6 percent, a reduction in slope of the air-breathing CO_2 response line (S_1) of

41.2 percent and a relative alkalemia denoted by the increase of 1.8 torr P_{A,CO_2} in parameter B. The reduction in D and S_1 is similar in extent to the maximum adaptation to hyperbaric exposure seen in previous work (2).

The sensitivity to hypoxia (parameter A) tended to remain constant during diver training, there being a small mean rise from 12.7 to 14.3 torr P_{A,O_2}. This overall rise in mean value was again solely due to subject number 7, the mean value of the other subjects falling very slightly from 12.4 to 12.0 torr P_{A,O_2}.

The results in subject 7 therefore tend to confirm the results seen in previous work (2) where a decrease in sensitivity to CO_2 inhalation was accompanied by an increase in hypoxia sensitivity following exposure to the hyperbaric environment. These results are contrary to those of Doell et al (1) who found a decrease in hypoxia sensitivity associated with decreased CO_2 response in men at 4 ATA. However, the disparity between the extent of the changes in CO_2 and hypoxia sensitivities confirms the observations of Doell et al that the respiratory response to hypoxia is much less sensitive to hyperbaric adaptation than is the response to CO_2.

The results of this investigation also suggest that adaptation to the hyperbaric environment only occurs in subjects with high initial sensitivities. It is assumed that adaptation could occur in subjects with low initial sensitivities but that the stress imposed on respiration in normal hyperbaric exposure is insufficient to cause such an adaptation. This observation could explain the conflicting reports in the literature.

CONCLUSIONS

One question posed before this work began was whether the known differences in respiratory response between divers and non-divers were the result of either adaptation to the hyperbaric environment or a process of natural selection. Previous work has shown that adaptation to the environment does occur and those findings are confirmed in subject 7 in this study. However, natural selection also probably occurs as, apart from subject 7, those candidates successful in diver training were drawn from a different population from those unsuccessful, the successful candidates having a naturally low sensitivity to CO_2 inhalation.

It is possible that success or failure in diver training may be linked to the ability of the candidate with a naturally high CO_2 sensitivity to adopt physiologically to a lower sensitivity. Subject 7 stated, on direct questioning, that he had frequently had respiratory distress during his training but that this had not been sufficiently severe to outweigh the attractions that diving held for him. Thus, it is evident that sensitivity to CO_2 is not pre-eminent among the stresses of diving but does contribute significantly to the total stress.

Another question which was posed at the start of this investigation was whether a test of CO_2 sensitivity could be used as a screening procedure to predict the likelihood of success in diver training. The advent of subject 7 shows that such a test could not be absolute but the results in other subjects would suggest that such a test could give significant results. The successful candidates (apart from number 7) all had mean CO_2 response curves in the absence of hypoxia of less than

2.0 l/min/torr P_{A,CO_2} while the unsuccessful candidates (apart from number 11) all had response curves of more than 2.4 l/min/torr P_{A,CO_2}. Subject number 11 was removed from training on his first dive because of symptoms of claustrophobia and his selection for the course could possibly have been avoided in a precourse interview. The data therefore suggest that the sensitivity to CO_2 of a diving trainee is negatively correlated with his likelihood of success in training, presumably as one factor influencing his sense of well-being in the hyperbaric environment.

The present work has been of value in showing that adaptation of the hyperbaric environment does occur and in dissociating the significant adaptation of CO_2 response from the small, or absent, adaptation to hypoxia.

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1. Doell, D., M. Zutter and N.R. Anthonisen. Ventilatory responses to hypercapnia and hypoxia at 1 and 4 ATA. Resp. Physiol. 18:338-346, 1973.
2. Young, J.M. Alteration of respiratory response to chemical stimuli following serial hyperbaric exposure. NMRI Report #1, M4306.02.7061BAM9, 1978.

Table 1. The values of the successful subjects (a) before and (b) after the diving course.

	(a) Before course					(b) After course				
Subject No.	S_1	A	B	C	D	S_1	A	B	C	D
1	2.26	50.2	33.4	19.6	1.85	1.49	14.3	30.5	32.6	1.29
	2.30	11.1	31.7	41.3	2.03	1.70	16.0	32.6	13.3	1.48
2	1.73	0.5	28.8	53.1	1.74	2.12	1.1	29.1	44.0	2.09
	1.80	0.02	27.1	52.6	1.80	2.81	33.8	35.7	38.1	2.69
3	2.06	0.1	33.0	52.8	2.06	1.95	12.3	25.6	6.9	1.79
	2.03	27.0	31.0	41.4	1.60	2.23	26.5	28.4	25.8	2.06
4	1.83	5.8	30.6	32.5	1.73	2.27	46.4	30.8	28.2	1.75
	1.29	0.05	21.6	51.6	1.29	2.30	17.5	30.7	60.6	1.71
5	2.12	1.4	30.4	61.5	2.08	1.47	10.2	26.1	11.9	1.35
	1.87	0.7	30.9	64.1	1.85	2.20	7.0	28.2	51.5	1.96
6	1.30	47.4	29.8	27.0	0.88	2.01	4.4	35.9	37.1	1.87
	1.93	5.0	31.6	46.0	1.82	1.97	7.4	33.6	35.1	1.75
7	4.64	2.5	32.2	49.5	4.51	3.27	16.0	35.3	34.4	2.91
	6.92	26.1	34.8	35.2	5.49	3.53	17.6	35.2	57.2	3.03
Mean	2.43	12.7	30.5	44.9	2.19	2.24	14.3	31.3	34.0	1.98

Units: S_1; 1/min/torr P_{A,CO_2}

A; torr P_{A,O_2}

B; torr P_{A,CO_2}

C; torr P_{A,O_2}

D; 1/min/torr P_{A,CO_2}

Table 2. Values before the course for those subjects who did not complete diver training.

Subject No.	S_1	A	B	C	D
8	3.09	30.9	35.6	39.0	2.32
	3.25	18.1	36.4	34.3	2.74
9	3.49	19.4	35.6	47.4	2.17
	3.93	15.3	34.9	59.7	2.73
10	2.75	13.3	33.6	27.8	2.44
	3.47	43.7	39.0	23.0	2.44
11	1.75	9.7	34.4	37.4	1.58
	2.02	45.0	34.5	16.1	1.75
12	2.73	16.0	31.7	15.1	2.40
	4.20	23.6	33.9	11.2	3.61
Mean	3.07	23.5	35.0	31.1	2.42